Predicting The Clinical Outcomes Of Intraarticular Distal Tibia Fractures Via A Fracture Energy Computation

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INTRODUCTION: High-energy distal tibia fractures involving the articular surface remain a significant treatment challenge for clinicians attempting to restore ankle function[1]. Post-traumatic osteoarthritis (PTOA) frequently follows, causing significant pain and loss of function[2]. Motor vehicle crashes are a primary cause of severe distal tibia fractures, but existing literature has not established how crash injury mechanisms and occupant protection offered by a vehicle influence fracture severity and long-term outcomes. Prior automotive safety literature has identified factors related to ankle injury risk, such as intrusion and occupant age, but few studies have specifically examined distal tibia fracture causation[3-5]. Furthermore, these studies categorized severity outcomes largely based on the threat-to-life posed by an injury, which lacks sensitivity for long-term injury morbidity. Previous studies analyzing long-term outcomes for intraarticular distal tibia fractures based upon their AO/OTA fracture classification found that complete articular fractures had worse outcomes than partial articular fractures[6]. An objective quantitative fracture severity metric accounting for pathomechanical factors not present in subjective categorical classification systems such as AO/OTA has recently been developed[7]. The total fracture energy imparted to the bone, soft tissue, and cartilage structures is estimated by computing the fracture-liberated (de novo) bone surface area and incorporating CT-inferred local bone density. This CT-derived fracture energy metric has been validated as a powerful prognostic tool for later PTOA development[8]. The goal of this study was to model clinical outcomes following a motor vehicle crash using the novel fracture energy computation to validate its use in crash injury analysis and identify crash-related factors associated with increased clinical distal tibia fracture severity.

METHODS: The Crash Injury Research and Engineering Network (CIREN) program reviews motor vehicle crashes involving occupants admitted to participating Level 1 trauma centers. CIREN collects injury CTs and detailed data regarding the crash event including vehicle characteristics, crash mechanics, and occupant demographics. For present purposes, CIREN cases with distal tibia fractures were selected using the Abbreviated Injury Scale, then filtered to control for confounding factors: only cases of frontal, non-rollover, non-ejection crashes were selected–crashes involving pregnant, rear-seated, or occupants younger than 14 years were excluded. After excluding cases with CT artifacts, 79 intraarticular distal tibia fractures (77 unilateral, 1 bilateral) were identified. Fractures were classified using AO/OTA grades by visualizing 3D reconstructions of each distal tibia fracture from CT. Fracture energies were computed according to previously presented methods using custom-written MATLAB code[7] (Figure 1A). Briefly, bone fragment surfaces were first identified and then classified as native or de novo based on CT intensities and local geometric character (surface roughness, curvatures). The de novo surface areas of all the fracture fragments were summed to provide a single aggregate measure of the fracture-liberated surface area. These fracture-liberated surface areas were scaled according to local bone density based on CT Hounsfield intensity to reflect the influence of bone density. Firth's logistic regression was used to determine the impact of fracture energy, vehicle model year, occupant age, and BMI on the likelihood an occupant suffered a complete articular fracture. The vehicle model year was binned at 2015 because newer vehicles have enhanced occupant compartment structures resistant to intrusions that significantly increase lower extremity injury risk[3]. Occupant age and BMI were binned at 55 years and 30 kg/m^2, respectively, since older age and obesity have previously been found to increase lower extremity injury risk[4].

RESULTS: Of the 19 cases for which fracture energy has so far been computed, 9 fractures were partial articular and 10 were complete articular. Four sampled occupants were male, and 15 were female. Their average age was 44.2±14.9 years, average BMI was 33.5±7.4 kg/m^2, and average fracture energy was 9.7±7.3 J. Figure 1B displays the results of the logistic regression, where the odds ratios indicate the impact of each predictor on the likelihood of complete articular fracture and the p-values indicate significance with a 5% alpha level. The only significant predictor was fracture energy, which was associated with a 58% increased risk of complete articular fracture for every 1 J increase in energy. Although odds ratios for vehicle model year, age, and BMI agreed with expected trends from previous literature[3,4], these relationships did not achieve statistical significance with the current sample.

DISCUSSION: Increasing fracture energy was a significant predictor of increased complete articular fracture risk, supporting the claim that increased energy is associated with worse clinical outcomes. Complete articular fractures often result in more de novo surface area, so a strong positive association with fracture energy was expected. Accordingly, the average fracture energy was 3.5±1.3 J and 15.3±5.6 J for partial and complete articular fractures respectively, indicating that the fracture energy metric is highly separated with respect to the AO/OTA fracture type. Firth's logistic regression was used to account for this separation to quantify the effect size of increasing fracture energy on the probability of complete articular fracture. The results of this study support the use of the CT-derived fracture energy to model pathomechanical factors of the crash event related to clinical injury severity. A limitation of this study is the small sample size, which limits the statistical power of the regression model. This restricts the number of predictor variables that can be included in the model and exaggerates error computations, reducing the significance of model predictors. Measuring fracture energy in the remaining CIREN distal tibia fractures will address this issue and lead to a more robust characterization of how vehicle model year, obesity and age influence fracture severity.

SIGNIFICANCE/CLINICAL RELEVANCE: The results of this study established a significant relationship between CT-derived fracture energy and AO/OTA distal tibia fracture classification. Higher fracture energy significantly increased the risk of complete articular fracture, linking pathomechanical factors of the crash event with clinical experience and supporting its potential use as a predictor of clinical outcomes in crash injury analysis.

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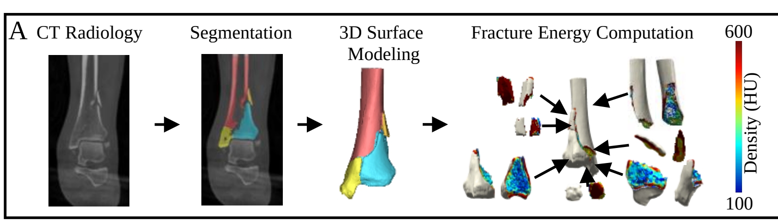

B

Predictor Variable	Odds Ratio	P-Value
Fracture Energy	1.58	0.025*
Newer Vehicle	0.081	0.31
Older Adult	4.69	0.57
Obese Occupant	2.53	0.52

Figure 1. A) FLE computation pipeline from CIREN CT radiology where 3D surface models are created for each fracture fragment and surfaces are classified as de novo or native bone. B) Firth's logistic regression model results.